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Greymont, 2000 Johannesburg (ZA). BOLLMANN, Annette [ZA/ZA]; 1638 Shillingford Road, Henley-on-Klip, 1962 Henley-on-Klip (ZA).

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(74) Agents: DUNLOP, Alan, J., S. et al.; Hahn &amp; Hahn Inc., 222 Richard Street, Hatfield, 0083 Pretoria (ZA).

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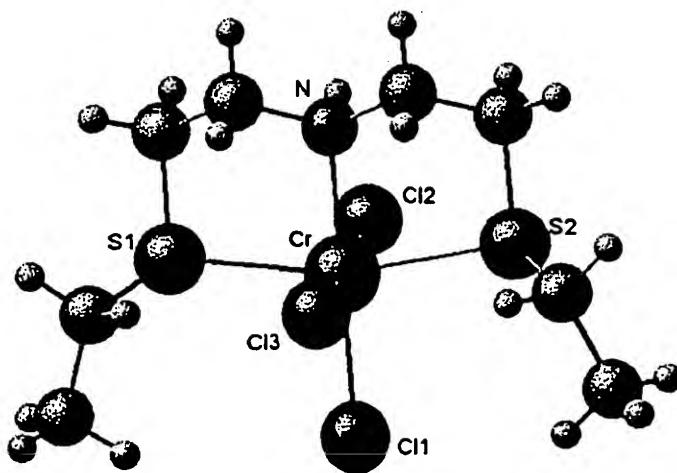
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(54) Title: TRIMERISATION AND OLIGOMERISATION OF OLEFINS USING A CHROMIUM BASED CATALYST



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(57) Abstract: The invention provides a mixed heteroatomic ligand for an oligomerisation of olefins catalyst, which ligand includes at least three heteroatoms, of which at least one heteroatom is sulfur and at least 2 heteroatoms are not the same. The invention also provides a multidentate mixed heteroatomic ligand for an oligomerisation of olefins catalyst, which ligand includes at least three heteroatoms of which at least one is a sulfur atom. The ligand may also contain, in addition to sulfur, at least one nitrogen or phosphorous heteroatom.

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## TRIMERISATION AND OLIGOMERISATION OF OLEFINS USING A CHROMIUM BASED CATALYST

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### FIELD OF THE INVENTION

This invention relates to a ligand and a catalyst system, more particularly an olefin oligomerisation or trimerisation catalyst system.

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### BACKGROUND OF THE INVENTION

The oligomerisation of olefins, primarily  $\alpha$ -olefins, with chromium catalysts has been extensively studied. More specifically, a number of chromium catalysts have been developed and used to trimerise olefins. In this regard, the trimerisation of ethylene to 1-hexene is significant since, in addition to its use as a specific chemical, 1-hexene is extensively used in polymerization processes either as a monomer or co-monomer. Furthermore, the trimeric products derived from longer chain olefins could be well utilized as synthetic lubricants (e.g. polyalphaolefins / PAOs), as well as various other applications such as components of drilling muds, and as feedstock to prepare detergents and plasticizers.

Prior art chromium based ethylene trimerisation processes include:

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- a) A process in which olefins are trimerised by passing the olefin in contact with a catalyst comprising the reaction product of a chromium compound, an organoaluminium compound hydrolyzed with a specific amount of water and a donor ligand selected from hydrocarbyl isonitriles, amines and ethers (US Patent No. 4,668,838);

b) A process to trimerise ethylene to 1-hexene comprising contacting ethylene with a stabilized catalyst system comprising a chromium source, a pyrrole-containing compound, a metal alkyl and an aromatic compound (European Patent No. 0 668 105);

5

c) A process for preparing  $\alpha$ -olefin oligomers, which comprises carrying out oligomerisation of an  $\alpha$ -olefin in a solvent by reacting said  $\alpha$ -olefin with a chromium-based catalyst system comprising a combination of at least a chromium compound, an amine or metal amide, and an alkylaluminium compound, in a contacting mode that the chromium compound and the alkylaluminium compound are not previously contacted with each other (US Patent No. 5,750,817);

10

d) A process for oligomerising ethylene to produce 1-butene and/or 1-hexene wherein catalytic composition is obtained by mixing at least one chromium compound with at least one aryloxy aluminium compound with general formula  $R_nAl(R'O)_{3-n}$  where R is a linear or branched hydrocarbyl radical containing 1 to 30 carbon atoms, R'O is an aryloxy radical containing 6 to 80 carbon atoms and n is a whole which can take the values 0,1 or 2, and with at least one other hydrocarbyl aluminium compound selected from tris(hydrocarbyl)aluminium compound or chlorinated or brominated hydrocarbyl aluminium compounds (US Patent No. 6,031,145); and

20

e) A process for the trimerisation of ethylene, said process comprising reacting ethylene, using a catalyst comprising an aluminoxane and a polydentate phosphine, arsenic and/or antimony coordination complex of a chromium salt, such that 1-hexene is formed (US Patent No. 5,811,618).

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## SUMMARY OF THE INVENTION

The invention is now described in general terms with reference to the accompanying drawings.

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In the drawings:

Figure 1 shows a X-Ray Crystal structure of  $\text{CrCl}_3(\text{bis-(2-ethylsulfanyl-ethyl)-amine})$ , and

Figure 2 shows a schematic representation (flow diagram) of one embodiment of  
10 a olefin oligomerisation process, in accordance with the invention.

This invention recognizes the need for a catalyst system, which facilitates the production of 1-hexene in high selectivity while avoiding the co-production of significant quantities of polyethylene. However, the catalyst system can also be  
15 used for the trimerisation or oligomerisation of other olefins, especially  $\alpha$ -olefins.

In this regard, it is known from the prior art (e.g. European Patent No. 537609) that chromium catalysts comprising a multidentate amine coordination complex of a chromium salt and an aluminoxane or an alkylaluminium compound are  
20 generally not particularly effective at trimerising ethylene selectively. This has also been established experimentally as is demonstrated in Example 1 below.

This invention generally relates to how the need for selectively producing 1-hexene from ethylene can be at least partly satisfied by using a chromium catalyst system containing a multidentate ligand with at least one amine functionality.

Thus, according to a first aspect of the invention there is provided a mixed heteroatomic ligand for the oligomerisation of olefins catalyst, which ligand  
30 includes at least three donor heteroatoms, of which at least one donor heteroatom is sulfur and at least 2 donor heteroatoms are not the same.

The ligand may be a multidentate mixed heteroatomic ligand which, includes at least three donor heteroatoms of which at least one is a sulfur atom.

5 The ligand may include, in addition to sulfur, at least one nitrogen or phosphorous donor heteroatom.

10 The ligand may be selected such that none of the non-carbon based donor heteroatoms are directly bonded to any of the other non-carbon based donor heteroatoms.

15 By "multidentate mixed heteroatomic" is meant a ligand that contains more than one non-carbon based donor atoms, of which one donor atom is different from the others and of which all the donor atoms are coordinated to the transition metal in the catalyst system. The applicant has found that it is important for catalyst activity that all the non-carbon based donor atoms coordinate with the transition metal, and the ligand therefore preferably, but not necessarily, needs at least one bridging atom between the donor atoms to provide the necessary distances between the donor atoms and to allow the ligand to assume the necessary spatial orientation for coordination of all donor atoms. Figure 1 20 contains the molecular structure of a complex between CrCl<sub>3</sub> and an example of such a multidentate mixed heteroatomic ligand, namely bis-(2-ethylsulfanyl-ethyl)-amine. Selected bond distances and angles of this molecular structure are summarized in Table 1.

**Table 1: Selected bond distances and angles of CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine)**

Chelate bite angle	83.07(5)°
	82.90(5)°
Cr-S bond distances	2.4508(7)Å
	2.4556(7)Å
Cr-N bond distance	2.1059(18)Å

5 As can be seen from Figure 1, this specific multidentate mixed heteroatomic ligand has a meridional arrangement in the complex, thereby enabling the formation of two Cr-S bonds with nearly equal bond distances (see Table 1). Such a meridional arrangement of the ligand is only possible if there is at least one bridging atom between the donor atoms. As could be expected, the resulting  
10 10 S-Cr-N chelate bite angles are also very similar in size.

Therefore a multidentate mixed heteroatomic ligand may also be selected such that none of the non-carbon based donor atoms are directly bonded to any of the other non-carbon based donor atoms.

15

The multidentate mixed heteroatomic ligand may be selected from the following ligand types:

20 a) R<sup>1</sup>A(R<sup>2</sup>BR<sup>3</sup>)(R<sup>4</sup>CR<sup>5</sup>) wherein R<sup>1</sup>, R<sup>3</sup> and R<sup>5</sup> may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxy carbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents; R<sup>2</sup> and R<sup>4</sup> may be the same or different and are C<sub>1</sub> to about C<sub>15</sub> hydrocarbyls; A is nitrogen or phosphorous; and B and C are sulfur or selenium; and  
25

5 b)  $R^1A(R^2BR^3R^4)(R^5CR^6)$  wherein  $R^1$ ,  $R^3$ ,  $R^4$ , and  $R^6$  may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxy carbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents;  $R^2$  and  $R^5$  may be the same or different and are  $C_1$  to about  $C_{15}$  hydrocarbyls; A and B are individually nitrogen or phosphorous; and C is sulfur; and

10 c)  $A(R^1BR^2R^3)(R^4CR^5)$  wherein  $R^2$ ,  $R^3$ , and  $R^5$  may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxy carbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents;  $R^1$  and  $R^4$  may be the same or different and are  $C_1$  to about  $C_{15}$  hydrocarbyls; B is nitrogen or phosphorous; and A and C are sulfur; and

15 d)  $A(R^1BR^2R^3)(R^4CR^5R^6)$  wherein  $R^2$ ,  $R^3$ ,  $R^5$  and  $R^6$  may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxy carbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents;  $R^1$  and  $R^4$  may be the same or different and are  $C_1$  to about  $C_{15}$  hydrocarbyls; B and C are individually nitrogen or phosphorous; and A is sulfur.

25 20 These multidentate mixed heteroatom based ligands can be synthesized according to procedures described in the literature, for example by A. Heßler *et al.*, *J. Organomet. Chem.*, 1998, **533**, 39-52, M. Tanaka *et al.* *J. Org. Chem.*, 2001, **66**, 7008-7012, M. Konrad, F. Meyer, K. Heinze, L. Zsolnai, *J. Chem. Soc., Dalton Trans.*, 1998 199-205 and G. Gelbard and P. Rumpf, *Bull. Soc. Chem.*, 30 1969, 1161-1170.

Specific examples of multidentate mixed heteroatom based ligands may include bis-(2-ethylsulfanyl-ethyl)-amine, bis-(2-methylsulfanyl-ethyl)-amine, bis-(2-butylsulfanyl-ethyl)-amine, bis-(2-decylsulfanyl-ethyl)-amine, bis-(ethylsulfanyl-methyl)-amine, bis-(2-ethylsulfanyl-phenyl)-amine, bis-(2-ethylsulfanyl-ethyl)-phosphine, bis-(2-ethylsulfanyl-ethyl)-ethylphosphine, bis-(2-ethylsulfanyl-ethyl)-phenylphosphine, N-methylbis-(2-ethylsulfanyl-ethyl)-amine, (2-ethylsulfanyl-ethyl)(3-ethylsulfanyl-propyl)-amine, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-amine, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-sulfide, (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-amine, (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-sulfide, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-ethylphosphine, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-phosphine, (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-ethylphosphine, (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-phosphine, bis-(2-diethylphosphino-ethyl)-sulfide, bis-(2-diethylamino-ethyl)-sulfide and (2-diethylphosphino-ethyl)(2-diethylamino-ethyl)-sulfide.

Suitable multidentate mixed heteroatomic ligands are bis-(2-ethylsulfanyl-ethyl)-amine and bis-(2-decylsulfanyl-ethyl)-amine and derivatives thereof.

The multidentate mixed heteroatomic ligands can be modified to be attached to a polymer chain (molecular wt. = 1000 or higher) so that the resulting transition metal complex is soluble at elevated temperatures, but becomes insoluble at 25°C. This approach would enable the recovery of the complex from the reaction mixture for reuse and has been used for other catalyst as described by D.E. Bergbreiter *et al.*, *J. Am. Chem. Soc.*, 1987, **109**, 177-179. In a similar vain these transition metal complexes can also be immobilized by bounding the multidentate mixed heteroatomic ligands to silica, silica gel, polysiloxane or alumina backbone as demonstrated by C. Yuanyin *et al.*, *Chinese J. React. Pol.*, 1992, **1**(2), 152-159 for immobilizing platinum complexes.

According to a further aspect of the invention, there is provided an oligomerisation of olefins catalyst system, which includes a mixed heteroatomic ligand, as described above.

5 The term "oligomerisation" generally refers to a reaction where all the monomer units of the oligomerisation product are the same. However, it may also include co-oligomerisation reactions where mixtures of olefins are used as the reagents thereby yielding products containing more than one type of monomer unit (i.e. different olefins). Such co-oligomerisation reactions often yield alkyl- and/or aryl-  
10 branched oligomeric products with distinct properties as demonstrated by C. Pelecchia *et al.*, *Macromolecules*, 2000, 33, 2807-2814.

The catalyst system may include a transition metal.

15 The transition metal may be chromium. Molybdenum, tungsten, titanium, nickel, and tantalum may also be used.

The catalyst system may include a combination of a mixed heteroatomic coordination complex of chromium and an aluminoxane.

20 The chromium coordination complexes which, upon mixing with an aluminoxane, catalyze ethylene trimerisation in accordance with the invention, may be suitably expressed by the formula  $LCrX_n$ , wherein X represents anions which can be the same or different, n is an integer from 0 to 5 and L is a mixed heteroatomic  
25 ligand.

The chromium precursor used in the preparation of the coordination complex may be selected from an organic or inorganic chromium compound, with the oxidation state of the chromium atom ranging from 0 to 6.

5 Chromium salts used in the preparation of the chromium coordination complex may be selected from chromium(III)acetylacetone, chromium (III) acetate, chromium (III) 2,2,6,6-tetramethylheptadionate, chromium (III) tris(2-ethylhexanoate, chromium (III) chloride, chromium (II) acetate, chromium (II) chloride, chromium (II) nitrate and chromium (III) sulphate.

10 Alternatively, organometallic complexes, for example, chromium trichloride tris-tetrahydrofuran complex, (benzene)tricarbonyl chromium, chromium hexacarbonyl, and the like, may be used in the preparation of the chromium coordination complex.

15 Aluminoxanes for use in the catalyst system can be prepared as known in the art by reacting water or water containing materials with trialkylaluminium compounds. Preferred aluminoxanes are prepared from trialkylaluminium compounds such as trimethylaluminium, triethylaluminium, tripropylaluminium, tributylaluminium, triisobutylaluminium, trihexylaluminium or the like, and mixtures thereof. Mixtures of different aluminoxanes may also be used in the catalyst system. Of these, the more preferred aluminoxane is prepared from trimethylaluminium and/or triethylaluminium. The use of said aluminoxane is 20 necessary to achieve catalytic activity.

25 The catalyst system may include, in addition to the aluminoxane or mixture of aluminoxanes, also a trialkylaluminium in amounts of between 0.01 to 100 mole per mole of aluminoxane. It should however be noted that aluminoxanes generally also contain considerable quantities of the corresponding trialkylaluminium compounds used in their preparation. The presence of these trialkylaluminium compounds in aluminoxanes can be attributed to their incomplete hydrolysis with water. Any quantity of a trialkylaluminium compound quoted in this disclosure is additional to alkylaluminium compounds contained 30 within the aluminoxanes.

The applicant has found that the triarylaluminium serves as a poisons scavenger to protect the aluminoxane and in some cases leads to an increase in the catalytic activity.

- 5 The aluminoxane may form part of a mixture of aluminoxanes. The applicant has found that at least a portion of the required more expensive methylaluminoxane can be replaced with a less expensive ethylaluminoxane, for example, and the resulting mixture shows the same, if not increased, catalytic activity.
- 10 The aluminoxane or mixture of aluminoxanes may preferably be selected from methylaluminoxane or ethylaluminoxane.

The chromium coordination complex and the aluminoxane may be combined in proportions to provide Al/Cr molar ratios of from about 1:1 to 10 000:1.

- 15 The hydrocarbon conversion catalyst system may be a trimerisation of  $\alpha$ -olefins or trimerisation of ethylene catalyst system.

- 20 The hydrocarbon conversion catalyst system described in this invention may also be used in combination with another catalyst system suitable for the polymerization of olefins. In such cases, the oligomerization or trimerisation products of the catalyst system disclosed in this invention could be incorporated into a polymer or other chemical product with desired properties. This concept of using dual catalyst systems, one for oligomerization and the other for 25 polymerization of olefins, to manufacture polyethylene copolymers has been demonstrated before for example by G. C. Bazan, Z.J.A. Komon and X. Bu, *J. Am. Chem. Soc.*, 2000, 122, 1830 and C. Pelecchia *et al.*, *Macromolecules*, 2000, 33, 2807-2814.

- 30 The catalyst system may be a trimerisation of  $\alpha$ -olefins or trimerisation of ethylene catalyst system.

The multidentate mixed heteroatomic coordination complex of a chromium salt may be either added to the reaction mixture, or generated in-situ. Known literature procedures can be used for the ex-situ preparation of such coordination complexes of a chromium salt. Examples of such procedures are described by

5 R.D Köhn and G.K. Köhn, *Angew. Chem. Int. Ed. Engl.*, 1994, 33(18), 1877-1878,  
R.D Köhn *et al.*, *Angew. Chem. Int. Ed.*, 2000, 39(23), 4337-4339 and P.  
Wasserscheid *et al.*, *Adv. Synth. Catal.*, 2001, 343(8), 814-818.

The catalyst system may include an inert solvent. These inert solvents include

10 any saturated aliphatic and unsaturated aliphatic and aromatic hydrocarbon and halogenated hydrocarbon. The saturated aliphatic and unsaturated aliphatic hydrocarbon compound can have any number of carbon atoms per molecule, but usually contain less than 20 carbon atoms due to commercial availability and end use. Preferred solvents include, but are not limited to, benzene, toluene, xylene,

15 ethylbenzene, mesitylene, heptane, nonane, cyclohexane, methylcyclohexane, 1-hexene, chlorobenzene, anisole and the like.

The individual components of the catalyst system described in this disclosure may be combined simultaneously or sequentially in any order, and in the

20 presence or absence of a solvent, in order to give an active catalyst. The mixing of the catalyst components can be conducted at any temperature between 0°C and 150°C. The temperature during the mixing of the catalyst components does not seem to have a significant effect on the catalyst performance. The presence of an olefin during the mixing of the catalyst components generally provides a

25 protective effect which may result in improved catalyst performance.

The chromium coordination complex and the aluminoxane are combined in proportions to provide Al/Cr molar ratios of from about 1:1 to 10 000:1, and preferably, from about 1:1 to 1000:1. In this respect, it was found that generally

30 significant lower Al/Cr molar ratios are required to achieve an acceptable catalyst

performance when the chromium coordination complex is completely soluble in the solvent employed for the oligomerisation reaction.

The catalyst system, or its individual components, may also be immobilized by supporting it on a heterogeneous surface such as silica, alumina, silica-alumina, MgO, zirconia or the like. This approach would also facilitate the recovery of the catalyst from the reaction mixture for reuse. The concept was successfully demonstrated with another chromium-based ethylene trimerisation catalyst by T. Monoi and Y. Sasaki, *J. Mol. Cat.A:Chem.*, 1987, 109, 177-179. In some cases, the heterogeneous surface (support) can also act as a catalyst component, for example where such supports contain aluminoxane functionalities or where the support is capable of performing similar chemical functions as an aluminoxane, which is for instance the case with IOLA<sup>TM</sup> (a commercial product from Davison Catalysts).

It was thus found that the hydrocarbon conversion catalyst system described in this invention suffered nearly no detectable decrease in its catalytic performance when alumina supported aluminoxane is used, instead of unsupported aluminoxane, during the preparation of the catalyst system.

According to a further aspect there is provided a process for the oligomerisation of olefins, the process including the step of contacting the olefins at pressures from atmospheric to 100 barg and at temperatures of from 0 °C to 200 °C, with a catalyst system as described above.

The process of this invention may also be carried out in an inert solvent. Any inert solvent that does not react with trialkylaluminium and aluminoxane compounds can be used. These inert solvents include any saturated aliphatic and unsaturated aliphatic and aromatic hydrocarbon and halogenated hydrocarbon. Preferred solvents include, but are not limited to, benzene, toluene, xylene, heptane, cyclohexane, 1-hexene and the like. The amount of

solvent is not exceptionally critical and generally ranges from about 50 to 99.9 wt % of the initial reaction mixture. Nevertheless, since the catalyst productivity tends to be somewhat higher at fairly low catalyst concentrations in the initial reaction mixture (typically in the range of 0.001-0.1 mmol Cr / 100ml reaction mixture), the catalyst concentration is chosen such that the catalyst productivity and selectivity is maximized.

The catalyst is dissolved in an inert solvent.

10 The process may include the step of generating the multidentate mixed heteroatomic complex of a chromium salt *in-situ* in a reaction mixture.

15 The process of this invention may be carried at pressures from atmospheric to 100 barg. Generally the process can be performed at any pressure within this range, but here again the actual reaction pressure is chosen such that the catalyst productivity and selectivity is maximized. Ethylene pressures in the range of 30-60 bar are particularly preferred.

20 The process of this invention may be carried out at temperatures from 0 °C to 200 °C. The process can normally be conducted at any temperature within this range, but as is the case with the ethylene pressure, the actual reaction temperature is chosen such that the catalyst productivity and selectivity is maximized. Temperatures in the range of 80-120 °C are particularly preferred.

25 The process may be carried out in the presence of an oxidizing agent such as oxygen or the like.

30 The process can normally be conducted at any temperature within this range, but as is the case with the ethylene pressure, the actual reaction temperature is chosen such that the catalyst productivity and selectivity is maximized. Temperatures in the range of 80-120 °C are particularly preferred.

5 The process may be carried out in the presence of an oxidizing agent such as oxygen or the like. In this respect it was found that the use of olefin reagents, such as ethylene, containing low quantities of oxygen (1 - 2000 parts per million) resulted in improvements in the performance of the catalyst system as well as in the product selectivity.

10 Although the catalyst, its individual components, reagents, solvents and reaction products are generally employed on a once-through basis, any of these materials can, and are indeed preferred to, be recycled to some extent in order to minimize 15 production costs.

This process may comprise, in combination a) a reactor, b) at least one inlet line into this reactor for olefin reactant and the catalyst system, c) effluent lines from 15 this reactor for oligomerisation reaction products, and d) at least one separator to separate the desired oligomerisation reaction products, wherein the catalyst system may include a multidentate mixed heteroatomic coordination complex of a chromium salt and an aluminoxane.

20 Figure 2 is a schematic representation (flow diagram) of one embodiment of this olefin oligomerisation process using three separators to separate the reaction products, solvent and spent catalyst (waste). While this drawing describes one embodiment of the invention for the purpose of illustration, the invention is not to be construed as limited by this schematic flow diagram, but the drawing is rather 25 intended to cover all changes and modifications within the spirit and scope thereof.

30 Various additional pumps, valves, heaters, coolers and other conventional equipment necessary for the practice of this invention will be familiar to one skilled in the art. These additional equipment have been omitted from Figure 2 for the sake of clarity.

The following description of the flow diagram shown in Figure 2 provides one method of operating the process, in accordance with the invention, and aims to give a further understanding of the aspects of this invention. As used in the description, "reactor effluent" refers to all components that can be removed from an oligomerisation reactor, including, but not limited to, unreacted olefin, catalyst system, oligomerisation product(s) and co-product(s). "Waste" refers to reaction co-product(s) with a higher molecular mass than the desired oligomerisation reaction product, polymeric products and the used catalyst system. "Product" refers to product(s) of the olefin oligomerisation reaction.

10

Olefin, and optionally oxygen or air, is fed through inlet line 7/8 into the oligomerisation reactor 1. Inlet line 5/6 introduces the catalyst system and optionally, solvent, into the oligomerisation reactor 1. Reactor effluent is removed from reactor 1 via line 9. It should be noted that lines 6, 8 and 9 can be located anywhere on the reactor 1. It is preferable that the contents in lines 9, 15, 16, 17 and 19 are maintained at a higher temperature in order to keep undesirable polymer particles from precipitating. The formation of such particles may have a detrimental effect on the operation of this process.

20 Line 9 introduces reactor effluent into separator 2 that separates unreacted olefin and reaction product(s) from higher boiling solvent(s), reaction product(s) and the used catalyst system. Lines 15/16 is an optional embodiment of the invention and can be used to facilitate the return of the higher boiling compounds in the reactor effluent, including the catalyst system, to reactor 1 via inlet line 6. Line 15/17  
25 transports an effluent stream, comprising higher boiling compounds and used catalyst system, from separator 2 to separator 4, which separates the solvent from all other compounds in this effluent stream. Line 18 is used to return the solvent to separator 2. Line 19 is an effluent line that transports waste from separator 4. Line 10 transports effluent comprising unreacted olefin and the  
30 major reaction product(s) from separator 2 to separator 3, that separates the unreacted olefin from the major reaction product(s).

Line 12/14 contains effluent comprising unreacted olefin and small quantities of very light boiling reaction product(s), e.g. 1-butene, and facilitates the recovery of the olefinic reagent by transporting it back to inlet line 6. Line 12/14 is a purge line containing unreacted olefin and small quantities of very light boiling reaction product(s) that is used to prevent a build up of very light boiling reaction product(s). Line 11 is an effluent line containing the major reaction product(s).

In another embodiment of the process the reactor and a separator may be combined to facilitate the simultaneous formation of reaction products and separation of these compounds from the reactor. This process principle is commonly known as reactive distillation when the reaction is a homogeneous liquid phase reaction. When the catalyst system exhibits no solubility in the solvent or reaction products, and is fixed in the reactor so that it does not exit the reactor with the reactor product, solvent and unreacted olefin, the process principle is commonly known as catalytic distillation.

The oligomerisation process described herein may be used in a process in which trimerisation and polymerization of ethylene occur simultaneously leading to the incorporation of the trimerisation products into a copolymer. One example of this type of process is described in US Patent No. 5,786,431.

## 25 EXAMPLES OF PERFORMING THE INVENTION

The invention will now be described with reference to the following examples which are not in any way intended to limit the scope of the invention.

30 In the examples that follow all procedures were carried out under inert conditions, using pre-dried reagents. Chemicals were obtained from Sigma-Aldrich Company

unless stated otherwise. All trialkylaluminium and aluminoxane compounds and solutions thereof were obtained from Crompton and Albemarle Corporation. In all the examples, the molar mass of methylaluminoxane (MAO) was taken to be 58.016 g/mol, corresponding to the (CH<sub>3</sub>-Al-O) unit, in order to calculate the 5 molar quantities of MAO used in the preparation of the catalyst systems described in the examples below. Similarly the molar mass of ethylaluminoxane (EAO) was taken as 72.042 g/mol, corresponding to the (CH<sub>3</sub>CH<sub>2</sub>-Al-O) building block. Ethylene oligomerisation reaction products were analyzed by GC-MS and GC-FID.

10

**Example 1: Reaction of CrCl<sub>3</sub>(pentamethyldiethylenetriamine)/MAO with ethylene**

The reaction was conducted in a 75 mL stainless steel autoclave equipped with 15 an addition funnel, gas inlet valve and a magnetic stirrer bar. The addition funnel was charged with 0.0149g (0.0449 mmol) of CrCl<sub>3</sub>(pentamethyldiethylenetriamine) dissolved in 20 mL of toluene and to the base of the autoclave was added 9.0 mL of 1.5M MAO solution in toluene. Over 20 minutes the base of the autoclave was heated to 100°C, after which time the reactor was charged with ethylene to a 20 pressure of 40 bar and the addition funnel was opened such that the Cr complex solution was allowed to mix with the MAO solution. After 30 minutes at a constant ethylene pressure of 40 bar the reaction was stopped by cooling the autoclave to 0°C and releasing excess ethylene. The gas released was collected and analysed by gas-chromatography (GC). The liquid contained in the autoclave 25 was quenched with ethanol followed by 10% hydrochloric acid, and nonane was added as a GC internal standard. The liquid/internal standard mixture was also analysed by GC. Both GC analyses indicated that 0.12g oligomers were formed of which 0.0048g (4 mass %) were hexene isomers. Filtration of the liquids gave 0.12g of polyethylene.

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**Example 2: Preparation of (bis-(2-ethylsulfanyl-ethyl)-amine)**

A solution of NaOH (6.0 g, 150 mmol) and ethanethiol (9.3 g, 150.0 mmol) in ethanol (150 ml) was added to a solution of bis(2-chloroethyl)amine hydrochloride (8.8g, 50.0 mmol) in ethanol (100 ml) at 0°C. The solution was stirred for 2 hours at 0°C, then overnight at r.t. After filtering, the filtrate was evaporated to dryness. The residue was taken up in 40-ml diethyl ether and filtered again. After evaporation of the solvent *in vacuo*, the product remained as a colourless semisolid. Yield: 5.39 g (56 %).  $^1\text{H-NMR}$  ( $\text{CDCl}_3$ )  $\delta$  1.20 (6H, t,  $\text{CH}_3$ ), 2.52 (1H, s, NH), 2.57 (4H, q,  $\text{SCH}_2\text{CH}_3$ ), 2.70 (4H, t,  $\text{SCH}_2$ ), 2.83 (4H, t,  $\text{NCH}_2$ ).

**Example 3: Preparation of (bis-(2-decylsulfanyl-ethyl)-amine)**

15 A solution of NaOH (3g , 75mmol) and decanethiol (15.5ml , 75mmol) in ethanol ( 75ml) was added to a solution of bis(2-chloroethyl)amine hydrochloride (4.4g ,25mmol) in ethanol (50 ml) at 0°C. The solution was stirred for 2 hours at 0°C and then for another 16 h at room temperature. After filtering, the filtrate was evaporated to dryness. The residue was taken up with dry ether and filtered again. After evaporation of the solvent under vacuum, the product remained as a colourless semi-solid. Yield: 9.4g (90%).  $^1\text{H-NMR}$  ( $\text{CDCl}_3$ )  $\delta$  0.87 (6H, t,  $\text{CH}_3$ ), 1.25-1.4 (28H, m,  $\text{SC}_2\text{H}_4\text{C}_7\text{H}_{14}\text{CH}_3$ ), 1.56 (4H, qn,  $\text{SCH}_2\text{CH}_2\text{C}_8\text{H}_{17}$  ), 1.88 (1H, s, NH), 2.52 (4H, qt,  $\text{SHCH}_2\text{C}_9\text{H}_{19}$ ), 2.69 (4H, t,  $\text{SCH}_2\text{CH}_2\text{NH}$ ), 2.82 (4H, t,  $\text{NCH}_2$ ).

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**Example 4: Preparation of  $\text{CrCl}_3(\text{bis-(2-ethylsulfanyl-ethyl)-amine})$** 

A solution of bis[2-(ethylsulfanyl)ethyl]amine (1.06 g, 5.5 mmol) in 20 ml THF was added to a solution of 1.87 g (5 mmol)  $\text{CrCl}_3(\text{THF})_3$  in 50 ml THF at room 30 temperature. The solution turned blue-green immediately and was stirred for 10 min, after which the solvent was removed *in vacuo* until about 25 ml remained. A

further 50-ml of diethyl ether was added, the solution was filtered and the solid washed, first with a mixture of diethyl ether and THF (50 ml each), then with a further 50 ml of diethyl ether. The solid was dried *in vacuo*. Yield: 1.28 g (72.6 %). Elemental analysis: Calculated for  $C_8H_{19}S_2NCl_3Cr$  (found): C 27.32 (26.97),  
5 H 5.45 (5.99), N 3.98 (3.64). Crystal data: monoclinic space group  $P21/c$ ,  $a = 7.6255(12)$ ,  $b = 13.059(5)$ ,  $c = 14.3703(10)$  Å,  $\beta = 90.790(11)^\circ$ ,  $V = 1430.9(6)$  Å<sup>3</sup>,  
Z = 4,  $D_C = 1.633$  g·cm<sup>-3</sup>,  $\mu = 1.622$  mm<sup>-1</sup>,  $F(000) = 724$ ,  $2\theta_{\max} = 54^\circ$ , 4013  
reflections, 3126 independent data. Convergence for 138 parameters at  $wR2 = 0.0857$ ,  $R1 = 0.0351$ ,  $GOF = 1.074$  for all data and  $R1 = 0.0309$  for 2846  
10 reflections with  $I > 2(I)$ . Residual electron density was 0.439 and -0.549 e·Å<sup>-3</sup>.  
Selected bond distances (Å) and angles (°): Cr-N 2.1059(18), Cr-S1 2.4508(7),  
Cr-S2 2.4556(7), Cr-Cl1 2.2985(8), Cr-Cl2 2.3184(7), Cr-Cl3 2.3167(7), N-Cr-S1  
83.07(5), N-Cr-S2 82.90(5), S1-Cr-Cl1 97.20(2), S2-Cr-Cl1 96.85(2), N-Cr-Cl1  
179.71(5), N-Cr-Cl2 85.82(6) and N-Cr-Cl3 88.64(6).

15

**Example 5: Preparation of  $CrCl_3$ (bis-(2-decylsulfanyl-ethyl)-amine)**

A solution of 3.93 g (9.4 mmol) of (bis-(2-decylsulfanyl-ethyl)-amine) in 80 ml THF was added to a solution of 3.21 g (8.6 mmol)  $CrCl_3$ (THF)<sub>3</sub> in 50 ml THF at  
20 room temperature. The solution turned blue-green immediately and was stirred  
for 10 min after which all the solvent was removed *in vacuo*. Diethylether (80 ml)  
was added to the residue and the solution was cooled overnight in a refrigerator.  
The solution was then filtered and the solid was washed with diethyl ether (3x60  
ml). The solid was dried *in vacuo*. Yield: 3.68 g (74.3 %). Elemental analysis:  
25 Calculated. for  $C_{24}H_{51}S_2NCl_3Cr$  (found): C 50.04 (50.23), H 8.86 (9.19), N 2.43.  
(2.16).

**Example 6: Ethylene trimerisation reaction using  $CrCl_3$ (bis-(2-ethylsulfanyl-ethyl)-amine)/MAO**

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CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine) (0.01407g, 0.04 mmol) was combined with 20 ml toluene in a Schlenk vessel and stirred for 5 minutes at room temperature. The resulting suspension was then transferred to a 300 ml pressure reactor (autoclave) containing a mixture of toluene (80ml) and MAO (methylaluminoxane, 27.2 mmol) at 90°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 100°C, while the ethylene pressure was kept at 40 barg. Thorough mixing was ensured throughout by mixing speeds of 1100 RPM's using a gas entraining stirrer. The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess ethylene from the autoclave, nonane or heptane was added as an internal standard for the analysis of the liquid phase by GC-FID. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid in water. A small sample of the organic layer was dried over anhydrous sodium sulfate and then analysed by GC-FID and GC-MS. The remainder of the organic layer was filtered to isolate the solid polymeric products. These solid products were dried overnight in an oven at 100°C and then weighed to yield 0.47 g of dry polymer. The GC analyses indicated that the reaction mixture contained 46.85.g oligomers. The product distribution of this example is summarized in Table 2.

**Example 7-19: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine)/MAO**

Examples 7 to 19 were carried out using the procedure of Example 6 above with variations in the reaction conditions, quantities of CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine) and MAO employed and the type of solvent used. The total volume of the reaction mixture at the start of each reaction was 100 ml throughout. The results obtained for these examples are summarized in Table 2.

**Example 20: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine)/MAO**

5 A 0.004 molar solution of CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine) in toluene (6 ml, 0.024 mmol) was transferred to a 300 ml pressure reactor (autoclave) containing a mixture of toluene (94 ml) and a MAO (methylaluminoxane, 1.12 mmol) at 80°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 90°C, while the ethylene pressure was  
10 kept at 30 barg. Thorough mixing was ensured throughout by mixing speeds of 1100 RPM using a gas entraining stirrer. The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess ethylene from the autoclave, nonane or heptane was added as an internal standard for the analysis of the liquid phase by  
15 GC-FID. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid in water. A small sample of the organic layer was dried over anhydrous sodium sulfate and then analysed by GC-FID. The remainder of the organic layer was filtered to isolate the solid polymeric products. These solid products were dried overnight in an oven at 100°C and then weighed  
20 to yield 0.09 g of dry polymer. The GC analyses indicated that the reaction mixture contained 43.90.g oligomers. The product distribution of this example is summarized in Table 3.

25 **Example 21-27: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine)/MAO**

Examples 21 to 27 were carried out using the procedure of Example 6 above with variations in the reaction conditions and the quantities of CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine) and MAO employed. The total volume of the reaction  
30

mixture at the start of each reaction was 100 ml throughout. The results obtained for these examples are summarized in Table 3.

5 **Example 28**

**Preparation of MAO on alumina**

Alumina (obtained from Sasol Chemie GmbH as Puralox SBa200) was calcined  
10 for 3 hours at 550°C under a nitrogen flow. The calcined alumina (4.80 g) was suspended in toluene (20 ml). MAO/toluene solution (1.068M, 14.53 mmol, 13.6 ml) was added slowly *via* a syringe to this alumina/toluene slurry and the resulting mixture was stirred for 2 hours at room temperature. The supernatant solvent was finally taken off with a syringe.

15

**Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine)/alumina supported MAO**

A 0.001097 molar solution of CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine) in toluene  
20 (21.88 ml, 0.024 mmol) was added to the alumina supported MAO (14.53 mmol on 4.80 g support). The resulting suspension was stirred at room temperature for 5 minutes whereafter it was transferred to a 300 ml pressure reactor (autoclave) containing toluene (78.1 ml) at 75°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 90°C, while the  
25 ethylene pressure was kept at 30 barg. Thorough mixing was ensured throughout by mixing speeds of 1100 RPM using a gas entraining stirrer. The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess ethylene from the autoclave, nonane or heptane was added as an internal standard for the analysis  
30 of the liquid phase by GC-FID. The two phases of the reaction mixture were separated and the liquid phase was analysed directly by GC-FID. The solid

particles in the reaction mixture was first exposed to air before being dried overnight in an oven at 100°C and then weighed. The mass of the dried solids was 5.48 g, indicating the formation of 0.65 g polymer during the reaction. The GC analyses indicated that the reaction mixture contained 40.99 g oligomers, of 5 which 0.4 mass % were butene isomers, 97.7 mass % were hexene isomers (99.6% being 1-hexene), 0.3 mass % were octene isomers and 0.5 mass % were decene isomers and heavier products.

10 **Example 29: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine)/MAO or used MAO**

A 300ml pressure vessel was connected to a vacuum pump *via* a stainless steel tube with two glass cold traps, a pressure gauge and a needle valve (to seal the 15 reactor off) between the vacuum pump and the reactor.

The following five steps were followed:

1) CrCl<sub>3</sub>(bis-(2-ethylsulfanyl-ethyl)-amine) (0.01055g, 0.03 mmol) was combined 20 with 20 ml toluene in a Schlenk vessel and stirred for 5 minutes at room temperature. The resulting suspension was then transferred to the pressure reactor containing a mixture of toluene (80ml) and a MAO (methylaluminoxane, 9.0 mmol) at 85°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 90°C, while the ethylene pressure was kept at 30 barg. Thorough mixing was ensured throughout by mixing speeds 25 of 1100 RPM using a gas entraining stirrer.

2) After 30 minutes, the temperature was decreased to 20 °C and the stirring rate to 300 rpm, whereafter the excess ethylene was released slowly, taking care to 30 introduce a nitrogen blanket into the reactor once the pressure had dropped below 1 barg. Once fully depressurized, the reactor was sealed off and the

needle valve leading to the cold traps and the vacuum pump was opened gradually until the pressure inside the reactor had decreased to 100 millibar under atmospheric pressure. At this point, the temperature of reaction mixture was also increased to 90 °C and a distillate formed which was collected in the

5 cold traps. As soon as the formation of the distillate ceased, the needle valve outlet to vacuum system was closed and the contents of the reactor was placed under a nitrogen blanket again. The estimated loss of toluene from the reactor during this flash distillation step was 33 ml.

10 3) New  $\text{CrCl}_3(\text{bis-(2-ethylsulfanyl-ethyl)-amine})$  (0.01055g, 0.03 mmol) was then added to the reactor as a suspension in toluene, but in 33 ml toluene (instead of the initial 20 ml) to ensure that the quantity of toluene in the reactor remains more or less constant at 100 ml. The pressure reactor was charged again with ethylene while the reactor temperature was maintained at 90°C and the ethylene

15 pressure kept at 30 barg. The mixing speed was also increased again to 1100 RPM.

4) Steps 2 and 3 were repeated another two times before moving onto step 5.

20 5) The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess ethylene from the autoclave, the contents of the reactor was combined with the contents of the cold traps and either nonane was added as an internal standard for the analysis of the liquid phase by GC-FID. The liquid contained in

25 the autoclave was quenched with ethanol followed by 10% hydrochloric acid in water. A small sample of the organic layer was dried over anhydrous sodium sulfate and then analysed by GC-FID. The remainder of the organic layer was filtered to isolate the solid polymeric products. These solid products were dried overnight in an oven at 100°C and then weighed to yield 0.70 g of dry polymer.

30 The GC analyses indicated that liquid phase contained 161.64 g oligomers, of which 97.9 mass % were hexene isomers (99.5% being 1-hexene).

**Example 30: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine)/EAO**

5 A 0.004 molar solution of CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine) in toluene (7.5 ml, 0.03 mmol) was transferred to a 300 ml pressure reactor (autoclave) containing a mixture of toluene (92.5 ml) and EAO (ethylaluminoxane, 30.0 mmol) at 80°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 90°C, while the ethylene pressure was  
10 kept at 30 barg. Thorough mixing was ensured throughout by mixing speeds of 1200 RPM using a gas entraining stirrer. The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess ethylene from the autoclave, nonane or heptane was added as an internal standard for the analysis of the liquid phase by  
15 GC-FID. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid in water. A small sample of the organic layer was dried over anhydrous sodium sulfate and then analysed by GC-FID. The remainder of the organic layer was filtered to isolate the solid polymeric products. These solid products were dried overnight in an oven at 100°C and then weighed  
20 to yield 2.37 g of dry polymer. The GC analyses indicated that the reaction mixture contained 9.52 g oligomers, of which 3.4 mass % were butene isomers, 85.5 mass % were hexene isomers (98.2% being 1-hexene), 0.8 mass % were octene isomers and 10.1 mass % were decene isomers and heavier products.

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**Example 31: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine)/EAO/TMA**

A 0.004 molar solution of CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine) in toluene (7.5 ml, 0.03 mmol) was transferred to a 300 ml pressure reactor (autoclave) containing a mixture of toluene (92.5 ml), EAO (ethylaluminoxane, 30.0 mmol)

and TMA (trimethylaluminium, 3.0 mmol) at 80°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 90°C, while the ethylene pressure was kept at 30 barg. Thorough mixing was ensured throughout by mixing speeds of 1200 RPM using a gas entraining stirrer.

5 The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess ethylene from the autoclave, nonane or heptane was added as an internal standard for the analysis of the liquid phase by GC-FID. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid in 10 water. A small sample of the organic layer was dried over anhydrous sodium sulfate and then analysed by GC-FID. The remainder of the organic layer was filtered to isolate the solid polymeric products. These solid products were dried overnight in an oven at 100°C and then weighed to yield 0.20 g of dry polymer. 15 The GC analyses indicated that the reaction mixture contained 23.90 g oligomers, of which 1.5 mass % were butene isomers, 96.1 mass % were hexene isomers (98.9% being 1-hexene), 0.6 mass % were octene isomers and 1.7 mass % were decene isomers and heavier products.

20 Example 32: Ethylene trimerisation reaction using CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine)/EAO/MAO

A 0.004 molar solution of CrCl<sub>3</sub>(bis-(2-decylsulfanyl-ethyl)-amine) in toluene (7.5 ml, 0.03 mmol) was transferred to a 300 ml pressure reactor (autoclave) 25 containing a mixture of toluene (92.5 ml), EAO (ethylaluminoxane, 8.55 mmol) and MAO (methylaluminoxane, 0.45 mmol) at 80°C. The pressure reactor was charged with ethylene after which the reactor temperature was maintained at 90°C, while the ethylene pressure was kept at 30 barg. Thorough mixing was ensured throughout by mixing speeds of 1200 RPM using a gas entraining stirrer. 30 The reaction was terminated after 30 minutes by discontinuing the ethylene feed to the reactor and cooling the reactor to below 10°C. After releasing the excess

ethylene from the autoclave, nonane or heptane was added as an internal standard for the analysis of the liquid phase by GC-FID. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid in water. A small sample of the organic layer was dried over anhydrous sodium sulfate and then analysed by GC-FID. The remainder of the organic layer was filtered to isolate the solid polymeric products. These solid products were dried overnight in an oven at 100°C and then weighed to yield 0.95 g of dry polymer. The GC analyses indicated that the reaction mixture contained 53.66 g oligomers, of which 0.2 mass % were butene isomers, 96.6 mass % were hexene isomers (99.5% being 1-hexene), 0.4 mass % were octene isomers and 2.7 mass % were decene isomers and heavier products.

Example 33: Ethylene trimerisation reaction using  $\text{CrCl}_3(\text{bis-(2-methylsulfanyl-ethyl)-amine})/\text{MAO}$

The reaction was conducted in a 75 mL stainless steel autoclave equipped with an addition funnel, gas inlet valve and a magnetic stirrer bar. The addition funnel was charged with 0.0039g (0.012 mmol) of  $\text{CrCl}_3(\text{bis-(2-methylsulfanyl-ethyl)-amine})$  dissolved in 20 mL of toluene and to the base of the autoclave was added 4.8 mL of 1.5M MAO solution in toluene. Over 20 minutes the base of the autoclave was heated to 80°C, after which time the reactor was charged with ethylene to a pressure of 40 bar and the addition funnel was opened such that the Cr complex solution was allowed to mix with the MAO solution. After 30 minutes at a constant ethylene pressure of 40 bar the reaction was stopped by cooling the autoclave to 0°C and releasing excess ethylene. The gas released was collected and analysed by GC. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid, and nonane was added as a GC internal standard. The liquid/internal standard mixture was also analysed by GC. Both GC analyses indicated that 12.9546 g oligomers were

formed of which 12.1773 g (94 mass %) were hexene isomers (99.7% being 1-hexene). Filtration of the liquids gave 0.0143 g of polyethylene.

5 **Example 34: Ethylene trimerisation reaction using  $\text{CrCl}_3((2\text{-ethylsulfanyl-ethyl})(3\text{-ethylsulfanyl-propyl})\text{-amine})/\text{MAO}$**

The reaction was conducted in a 75 mL stainless steel autoclave equipped with an addition funnel, gas inlet valve and a magnetic stirrer bar. The addition funnel 10 was charged with 0.0039g (0.0107 mmol) of  $\text{CrCl}_3((2\text{-ethylsulfanyl-ethyl})(3\text{-ethylsulfanyl-propyl})\text{-amine})$  dissolved in 20 mL of toluene and to the base of the autoclave was added 4.3 mL of 1.5M MAO solution in toluene. Over 20 minutes 15 the base of the autoclave was heated to 80°C, after which time the reactor was charged with ethylene to a pressure of 40 bar and the addition funnel was opened such that the Cr complex solution was allowed to mix with the MAO solution. After 30 minutes at a constant ethylene pressure of 40 bar the reaction 20 was stopped by cooling the autoclave to 0°C and releasing excess ethylene. The gas released was collected and analysed by GC. The liquid contained in the autoclave was quenched with ethanol followed by 10% hydrochloric acid, and nonane was added as a GC internal standard. The liquid/internal standard mixture was also analysed by GC. Both GC analyses indicated that 4.0487. g oligomers were formed of which 3.2795 g (81 mass %) were hexene isomers (97.9% being 1-hexene). Filtration of the liquids gave 0.0600 g of polyethylene.

Table 2: Ethylene trimerisation reactions using  $\text{CrCl}_3(\text{bis}(2\text{-ethylsulfanyl-ethyl})\text{-amine})/\text{MAO}$ 

Example	$\text{CrCl}_3$ complex (mg)	Cr (mmol)	MAO (mmol)	Temp (°C)	Pressure (bars)	Activity (g prod/ g Cr)	Total Product (g)	Solids (Wt %)	Liquids (Wt %)	Liquid Product Distribution (Wt %)			1-Hexene in $\text{C}_6$ (Wt %)
										$\text{C}_4$	$\text{C}_6$	$\text{C}_8$	$\text{C}_{10+}$
6	15.5	0.044	29.9	100	40	21767	49.80	0.58	99.00	0.3	96.0	0.5	2.5
7	15.5	0.044	29.9	40	40	2750	6.29	13.40	86.60	0.2	91.8	2.5	2.3
8	15.5	0.044	29.9	140	40	1700	3.89	19.40	80.60	0.8	94.1	0.8	1.3
9 <sup>1</sup>	15.5	0.044	29.9	90	40	6580	15.05	7.90	92.10	0.8	95.2	1.0	1.5
10	15.5	0.044	29.9	100	10	4424	10.12	2.49	97.51	0.8	94.2	0.7	2.8
11	15.5	0.044	29.9	100	50	23954	54.80	1.78	98.22	0.5	94.8	0.8	2.9
12	3.9	0.011	7.5	100	40	40503	23.17	0.60	99.40	0.1	98.5	0.4	0.7
13	15.5	0.044	9.0	100	40	11500	26.31	3.07	96.93	0.1	99.2	0.4	0.5
14	10.6	0.030	9.0	90	30	32459	50.63	0.03	99.97	0.2	96.2	0.5	2.9
15	4.2	0.012	3.6	90	30	44242	27.60	0.30	99.70	0.1	97.7	0.4	1.6
16	10.6	0.030	3.6	90	30	18116	28.26	0.76	99.24	0.1	97.8	0.4	1.5
17	1.4	0.004	1.1	85	30	96251	20.02	0.16	99.84	0.1	98.5	0.5	0.8
18	4.2	0.012	2.4	85	50	59312	37.01	0.10	99.90	0.1	98.0	0.7	1.1
19	10.6	0.030	3.6	85	15	23784	37.10	0.18	99.82	0.1	95.5	0.3	3.9
													99.4

<sup>1</sup> Cyclohexane was used as the solvent in this reaction

Table 3: Ethylene trimerisation reactions using  $\text{CrCl}_3(\text{bis-(2-decylsulfanyl-ethyl)-amine})/\text{MAO}$ 

Example	$\text{CrCl}_3$ complex (mg)	Cr (mmol)	MAO (mmol)	Temp (°C)	Pressure (bars)	Activity (g prod/ g Cr)	Total Product (g)	Solids (Wt %)	Liquids (Wt %)	Liquid Product Distribution (Wt %)				1-Hexene in $\text{C}_4$ (Wt %)
										$\text{C}_4$	$\text{C}_6$	$\text{C}_8$	$\text{C}_{10}^+$	
20	13.8	0.024	14.40	90	30	35250	43.99	0.21	99.79	0.4	97.5	0.4	1.3	99.4
21	15.0	0.026	2.60	90	30	38796	52.45	0.30	99.70	0.1	96.7	0.4	2.8	99.5
22	15.0	0.026	1.30	90	45	20327	27.48	2.44	97.56	0.4	94.8	0.8	3.8	99.7
23	6.9	0.012	1.20	100	45	71018	44.31	0.30	99.70	0.2	97.5	0.6	1.5	98.7
24	6.9	0.012	0.60	90	47	31700	19.78	1.05	98.95	0.2	96.6	0.5	1.4	99.7
25	4.6	0.008	0.40	90	45	44000	18.30	0.67	99.33	0.1	98.7	0.8	0.4	99.7
26	6.9	0.012	0.36	90	45	46350	28.92	2.37	97.63	0.1	98.4	0.6	0.9	99.7
27	6.9	0.012	0.36	90	45	37650	23.49	0.49	99.51	0.1	97.9	0.6	1.3	99.7

**Claims**

1. A mixed heteroatomic ligand for an oligomerisation of olefins catalyst, which ligand includes at least three heteroatoms, of which at least one heteroatom is sulfur and at least 2 heteroatoms are not the same.  
5
2. A multidentate mixed heteroatomic ligand for an oligomerisation of olefins catalyst, which ligand includes at least three heteroatoms of which at least one is a sulfur atom.  
10
3. A ligand as claimed in Claim 1 or Claim 2, which contains, in addition to sulfur, at least one nitrogen or phosphorous heteroatom.  
15
4. A ligand as claimed in any of the previous claims, wherein the ligand is selected such that none of the non-carbon based heteroatoms are directly bonded to any of the other non-carbon based heteroatoms.  
15
5. A ligand as claimed in Claim 4, wherein the ligand is selected from the following ligand types:  
20
- (a)  $R^1A(R^2BR^3)(R^4CR^5)$  wherein  $R^1$ ,  $R^3$  and  $R^5$  may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxycarbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents;  $R^2$  and  $R^4$  may be the same or different and are  $C_1$  to about  $C_{15}$  hydrocarbys;  $A$  is nitrogen or phosphorous; and  $B$  and  $C$  are sulfur; and  
25
- (b)  $R^1A(R^2BR^3R^4)(R^5CR^6)$  wherein  $R^1$ ,  $R^3$ ,  $R^4$ , and  $R^6$  may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxycarbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents;  $R^2$  and  $R^5$  may be the same or different and are  $C_1$   
30

to about C<sub>15</sub> hydrocarbyls; A and B are individually nitrogen or phosphorous; and C is sulfur; and

5 (c) A(R<sup>1</sup>BR<sup>2</sup>R<sup>3</sup>)(R<sup>4</sup>CR<sup>5</sup>) wherein R<sup>2</sup>, R<sup>3</sup>, and R<sup>5</sup> may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxy carbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents; R<sup>1</sup> and R<sup>4</sup> may be the same or different and are C<sub>1</sub> to about C<sub>15</sub> hydrocarbyls; B is nitrogen or phosphorous; and A and C are 10 sulfur; and

15 (d) A(R<sup>1</sup>BR<sup>2</sup>R<sup>3</sup>)(R<sup>4</sup>CR<sup>5</sup>R<sup>6</sup>) wherein R<sup>2</sup>, R<sup>3</sup>, R<sup>5</sup> and R<sup>6</sup> may be hydrogen or independently be selected from the groups consisting of alkyl, aryl, aryloxy, halogen, nitro, alkoxy carbonyl, carbonyloxy, alkoxy, aminocarbonyl, carbonylamino, dialkylamino, or derivatives thereof, or aryl substituted with any of these substituents; R<sup>1</sup> and R<sup>4</sup> may be the same or different and are C<sub>1</sub> to about C<sub>15</sub> hydrocarbyls; B and C are individually nitrogen or phosphorous; and A is sulfur.

20 6. A ligand as claimed in Claim 2, wherein the ligand is selected from bis-(2-ethylsulfanyl-ethyl)-amine, bis-(2-methylsulfanyl-ethyl)-amine, bis-(2-butylsulfanyl-ethyl)-amine, bis-(2-decylsulfanyl-ethyl)-amine, bis-(2-butylsulfanyl-ethyl)-amine, bis-(2-decylsulfanyl-ethyl)-amine, bis-(ethylsulfanyl-methyl)-amine, bis-(2-ethylsulfanyl-phenyl)-amine, bis-(2-ethylsulfanyl-ethyl)-phosphine, bis-(2-ethylsulfanyl-ethyl)-ethylphosphine, bis-(2-ethylsulfanyl-ethyl)-phenylphosphine, N-methylbis-(2-ethylsulfanyl-ethyl)-amine, (2-ethylsulfanyl-ethyl)(3-ethylsulfanyl-propyl)-amine, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-amine, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-sulfide, (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-amine and (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-sulfide, (2-ethylsulfanyl-ethyl)(2-diethylphosphino-ethyl)-phosphine, (2-ethylsulfanyl-ethyl)(2-diethylamino-ethyl)-ethylphosphine, bis-(2-diethylphosphino-ethyl)-sulfide, bis-(2-diethylamino-ethyl)-sulfide, (2-diethylphosphino-ethyl)(2-diethylamino-ethyl)-sulfide and derivatives thereof.

7. A ligand as claimed in any one of the previous claims, wherein the oligomerisation catalyst system is a trimerisation of  $\alpha$ -olefins catalyst system.

5 8. A ligand as claimed in any one of the previous claims, wherein the oligomerisation catalyst system is a trimerisation of ethylene to 1-hexene catalyst system.

10 9. An oligomerisation of olefins catalyst system, which includes a mixed heteroatomic ligand, as claimed in any one of the previous claims, and a transition metal.

15 10. A catalyst system as claimed in claim 9, wherein the transition metal is chromium.

20 11. A catalyst system as claimed in Claim 10, which includes a combination of an aluminoxane and a mixed heteroatomic coordination complex of chromium.

12. A catalyst system as claimed in Claim 11, wherein the aluminoxane forms part of a mixture of aluminoxanes.

25 13. A catalyst system as claimed in Claim 12, wherein the chromium coordination complex is expressed by the formula  $LCrX_n$ , wherein X represents anions which can be the same or different, n is an integer from 0 to 5 and L is a mixed heteroatomic ligand.

30 14. A catalyst system as claimed in any one of claims 11 to 13, wherein the chromium source for the preparation of the coordination complex is selected from an organic or inorganic chromium compound, with the oxidation state of the chromium atom ranging from 0 to 6.

15. A catalyst system as claimed in any one of claims 11 to 14, wherein a chromium salt is used in the preparation of the catalyst system and the

chromium salt is selected from chromium(III)acetylacetone, chromium (III) acetate, chromium (III) 2,2,6,6-tetramethylheptadionate, chromium (III) tris(2-ethylhexanoate, chromium (III) chloride, chromium (II) acetate, chromium (II) chloride, chromium (II) nitrate and chromium (III) sulphate.

5

16. A catalyst system as claimed in any one of claims 11 to 15, wherein each aluminoxane is prepared from a trialkylaluminium.

10 17. A catalyst system as claimed in any one of claims 11 to 16, which includes, in addition to the aluminoxane or mixture of aluminoxanes, also a trialkylaluminium.

15 18. A catalyst system as claimed in any one of claims 11 to 17, wherein the aluminoxane or mixture of aluminoxanes are selected from methylaluminoxane and ethylaluminoxane.

19. A catalyst system as claimed in Claim 17, which includes a trialkylaluminium compound in amounts of between 0.1 to 100 mole per mole of aluminoxane.

20

20. A catalyst system as claimed in any one of claims 11 to 19, wherein the chromium coordination complex and the aluminoxane are combined in proportions to provide Al/Cr molar ratios of from about 1:1 to 10 000:1.

25 21. A process for the oligomerisation of olefins, the process including the step of contacting the olefins at pressures from atmospheric to 100 barg and at temperatures of from 0 °C to 200 °C, with a catalyst system as claimed in any of claims 9 to 20.

30 22. A process as claimed in claim 21, wherein the olefins are contacted with the catalyst system at pressures from 30 to 50 barg and at temperatures of from 80 °C to 100 °C.

23. A process as claimed in Claim 22, wherein the catalyst is dissolved in an inert solvent.
24. A process as claimed in any one of claim 21 to 23, which includes the 5 step of generating the multidentate mixed heteroatomic complex of a chromium salt in-situ in a reaction mixture.
25. A ligand substantially as described herein.
- 10 26. A catalyst system substantially as described herein.
27. A process substantially as described herein.

1/1

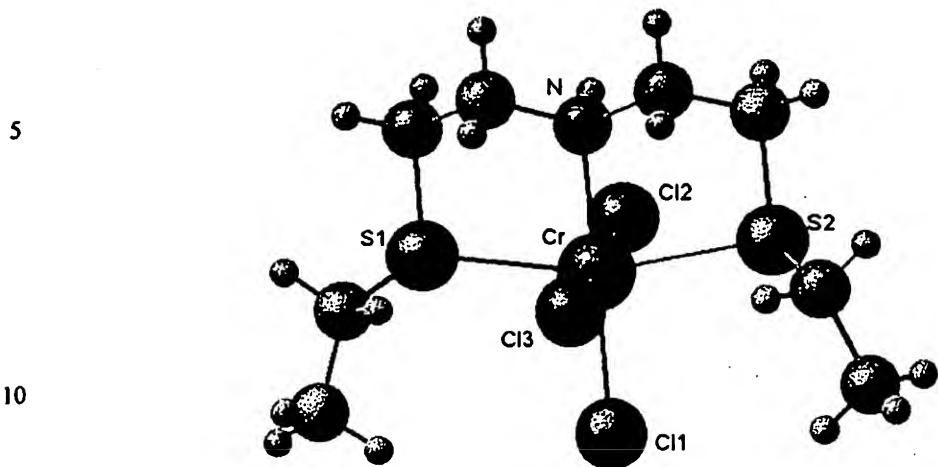


Figure 1

15

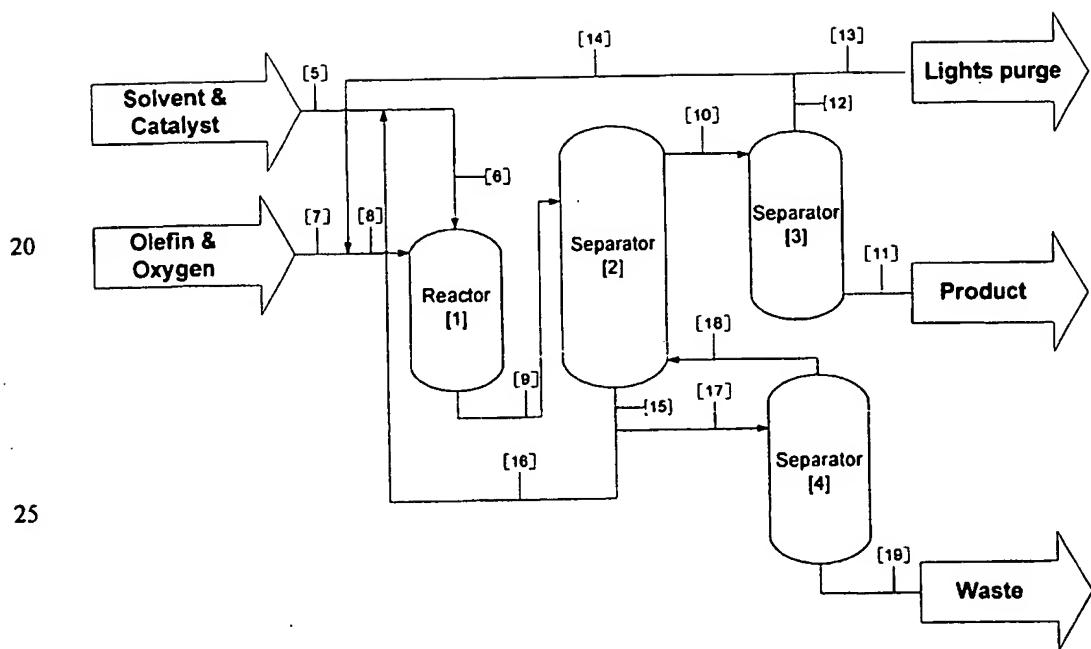


Figure 2

## INTERNATIONAL SEARCH REPORT

I	nternational Application No PCT/ZA 02/00216
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A. CLASSIFICATION OF SUBJECT MATTER		
IPC 7	C07C2/32	C07C323/25

According to International Patent Classification (IPC) or to both national classification and IPC		
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B. FIELDS SEARCHED		
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Minimum documentation searched (classification system followed by classification symbols)		
IPC 7	C07C	

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
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Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
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EPO-Internal, BEILSTEIN Data, WPI Data, PAJ, CHEM ABS Data		
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C. DOCUMENTS CONSIDERED TO BE RELEVANT		
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Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>KONRAD, M ET AL : "Unsymmetrically substituted pyrazolates: nickel(II) complexes of a novel dinucleating ligand providing both N- and S-rich co-ordination spheres"</p> <p>JOURNAL OF THE CHEMICAL SOCIETY, DALTON TRANSACTIONS.,</p> <p>1998, pages 199-205, XP002237101</p> <p>CHEMICAL SOCIETY. LETCHWORTH., GB</p> <p>ISSN: 1472-7773</p> <p>cited in the application scheme 1, compounds I, HL1</p> <p>---</p> <p style="text-align: center;">-/-</p>	1-8

<input checked="" type="checkbox"/>	Further documents are listed in the continuation of box C.
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<input checked="" type="checkbox"/>	Patent family members are listed in annex.
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## \* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

- \*&\* document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the International search report
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3 April 2003	17/04/2003
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Name and mailing address of the ISA	Authorized officer
-------------------------------------	--------------------

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl. Fax: (+31-70) 340-3016	O'Sullivan, P
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## INTERNATIONAL SEARCH REPORT

In: International Application No

PCT/ZA 02/00216

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TANAKA, M ET AL : "Synthesis and metal-ion binding properties of monoazathiacycrown ethers" JOURNAL OF ORGANIC CHEMISTRY., vol. 66, no. 21, 2001, pages 7008-7012, XP002237102 AMERICAN CHEMICAL SOCIETY, WASHINGTON, DC., US ISSN: 0022-3263 cited in the application schemes 6 and 7 ---	1-8
X	FRIEBE, M ET AL: "Neutral '3+1' mixed-ligand oxorhenium(V) complexes with tridentate 'S,N,S' chelates and aminoalkanethiols: synthesis, characterisation and structure determination" JOURNAL OF THE CHEMICAL SOCIETY, DALTON TRANSACTIONS., 2000, pages 2471-2475, XP002237103 CHEMICAL SOCIETY. LETCHWORTH., GB ISSN: 1472-7773 scheme 2 ---	1-8
X	COOPER, T H ET AL : "Kinetic and thermodynamic measurements on branched amino polythiaether ligands: a family of complexing agents analogous to EDTA and NTA exhibiting enhanced selectivity for copper (II)" INORGANIC CHEMISTRY., vol. 31, no. 18, 1992, pages 3796-3804, XP002237104 AMERICAN CHEMICAL SOCIETY. EASTON., US ISSN: 0020-1669 figure 1: TEMED, TMMEA, TEMA, TMMPA, TEMPA ---	1-4
A	WO 01 83447 A (DIXON JOHN THOMAS ; GROVE JACOBUS JOHANNES CRONJE (ZA); RANWELL ALT) 8 November 2001 (2001-11-08) page 1, line 15 - line 25 page 3, line 21 - line 23 page 6, line 19 - line 28 ---	1-25
A	EP 0 537 609 A (ETHYL CORP) 21 April 1993 (1993-04-21) cited in the application examples ---	1-25
		-/-

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/ZA 02/00216

## C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE CROSSFIRE BEILSTEIN 'Online! Beilstein Institut zur Förderung der Chemischen Wissenschaften, Frankfurt am Main, DE; Database accession no. 2441430 XP002237105 abstract & BAL, S ET AL: POLISH JOURNAL OF CHEMISTRY., vol. 54, no. 4, - 1980 pages 837-842, POLISH CHEMICAL SOCIETY., XX ----	1-8
X	DATABASE CROSSFIRE BEILSTEIN 'Online! Beilstein Institut zur Förderung der Chemischen Wissenschaften, Frankfurt am Main, DE; Database accession no. 1978690 XP002237106 abstract & WEHRMEISTER, H L: JOURNAL OF ORGANIC CHEMISTRY., vol. 28, 1963, pages 2589-2591, AMERICAN CHEMICAL SOCIETY, WASHINGTON, DC., US ISSN: 0022-3263 -----	1-8

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/ZA 02/00216

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.: 25-27 because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:  
see FURTHER INFORMATION sheet PCT/ISA/210
  
3.  Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1.  As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
  
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
  
3.  As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
  
4.  No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

## FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 25-27

Present claims 1-25 relate to an extremely large number of possible ligands, catalyst systems comprising these ligands and processes incorporating said catalyst systems. Support within the meaning of Article 6 PCT and/or disclosure within the meaning of Article 5 PCT is to be found, however, for only a very small proportion of the compounds/systems/processes. The application only contains 4 examples, all containing a central N atom separated by a saturated alkyl chain of 1-3 carbon from 2 S atoms. All of the examples may be covered by the general formula:

$N((CH_2)_{1-3}SR)_2$  where R is a saturated linear alkyl chain.

In the present case, the claims so lack support, and the application so lacks disclosure, that a meaningful search over the whole of the claimed scope is impossible. Consequently, the search has been carried out for those parts of the claims which appear to be supported and disclosed, namely those parts of the claims relating to the following ligands:

R1A(R2BR3)(R4CR5) of claim 5 (a) where:

A = N  
B = S  
C = S

R2 and R4 are  $-(CH_2)_{1-4}-$   
R1, R3 and R4 are defined in claim 5(a)

and their corresponding use in catalyst systems and processes as defined in the claims.

Claims 25-27 have not been searched since they refer back to unspecified parts of the claims and/or description and do not clearly define the subject-matter for which protection is sought.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

## INTERNATIONAL SEARCH REPORT

## Information on patent family members

International Application No

PCT/ZA 02/00216

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
WO 0183447	A 08-11-2001	AU WO	6352601 A 0183447 A2	12-11-2001 08-11-2001
EP 0537609	A 21-04-1993	CA DE DE EP JP JP US US US US	2079399 A1 69212761 D1 69212761 T2 0537609 A2 3217500 B2 5221882 A 5968866 A 5550305 A 5811618 A 5744677 A	17-04-1993 19-09-1996 02-01-1997 21-04-1993 09-10-2001 31-08-1993 19-10-1999 27-08-1996 22-09-1998 28-04-1998

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